



Analysis of the Effectiveness of Monitoring Ship Fuel Consumption at PT XYZ in Jakarta Using the Vessel Monitoring System (VMS)

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Abstract. This study aims to analyze the effectiveness of fuel consumption monitoring using a Vessel Monitoring System (VMS) as a measurement tool based on operational vessel data. The analysis utilizes voyage speed, travel duration, and route distance to estimate fuel consumption and evaluate its suitability as a monitoring instrument. The method used is descriptive quantitative with the use of secondary data owned by shipping company. VMS data were analyzed and compared with manual fuel consumption reports to assess the system's capability in supporting fuel monitoring activities. The findings indicate that fuel consumption recording currently relies on manual liters-per-hour method, while the VMS has not been optimally utilized as an analytical tool. Vessel speed was found to be associated with fuel consumption; however, its application as an estimation basis still requires contextual validation. Based on 49 voyage records, VMS-based model achieved an average agreement rate of 76.38% compared with manual reports, indicating that the system can provide a reasonable level of operational accuracy. The model is therefore more suitable as an initial verification and monitoring tool rather than as a standalone estimation method. This study demonstrates the potential VMS utilization as a digital monitoring tool for fuel consumption in the shipping industry by incorporating operational factors such as speed and voyage distance. The implementation of VMS-based monitoring supports digital transformation in maritime logistics through a data-driven approach to operational efficiency evaluation. Improved fuel monitoring contributes to energy efficiency initiatives and has the potential to support emission reduction strategies in sustainable shipping operations.

Keywords: Digital Transformation, Fuel, Maritime Logistics, Sustainable Shipping, Vessel Monitoring System Introduction

1. Introduction

The shipping industry is a transportation sector that plays a crucial role in supporting logistics activities in both global and domestic trade. The maritime transportation sector serves as the backbone of goods distribution, as the majority of international trade flows through sea, reflecting the high dependence of the global economy on shipping (United Nations Conference on Trade and Development, 2024). With the advancement of digital technology, information technology-based ship operational monitoring systems have begun to be widely implemented to improve operational efficiency and transparency. One widely used technology is the Vessel Monitoring System (VMS), a satellite-based ship monitoring system capable of providing real time information on a ship's position, speed, and activity (Bachtiar, 2022). Initially, this system was primarily used for monitoring and shipping safety, but over time, it has also been utilized as a tool for operational control and management decision-making (Food and Agriculture Organization, 2018). The effectiveness of ship monitoring systems is becoming increasingly important, as the resulting operational data can be used for reporting, performance evaluation, and operational cost control (Setiawan et al., 2025). In another statement, it is stated that a data-based approach enables shipping companies to identify operational potential and make continuous improvements, thus making a real contribution to increasing over all shipping productivity and efficiency (Setiawan et al., 2025).

Fuel consumption is heavily influenced by the route, speed, and duration of a voyage, making it a dominant factor in the operational cost structure of shipping. The use of sensor based and digital monitoring systems has been reported to increase transparency in fuel usage and reduce potential waste (Wang et al., 2021). Although monitoring technologies such as VMS are widely used, their implementation in industry practice still focuses more on tracking vessel position than on their use for operational efficiency analysis, such as monitoring fuel consumption.

PT XYZ is engaged in shipping or shipping in the form of sea transportation rental by having two (2) types of ships, namely LCT (Land Craft Tank) and CPO (Crude Palm Oil). These two ships have different types of transportation functions, the LCT ship itself usually transports heavy equipment such as HD-785 dump trucks, PC-2000 excavators and others, while the CPO ship transports crude oil (palm oil). In its activities, the company has problems related to the ineffectiveness of recording fuel consumption. The difference that arises if the daily recording of fuel consumption in a shipment can cause miscalculations in making consumption estimates later in actual conditions that occur in the field.

Table 1. Summary of Fuel Consumption per Period

PERIOD	ESTIMATION (LITER)	ACTUAL (LITER)	DIFFERENCE (LITER)	OVER COUNT	UNDER COUNT	TOTAL VOYAGE
JAN-25	126.200	127.879	1.679	4	2	6
FEB-25	149.957	156.512	6.555	5	1	6
MAR-25	112.565	129.497	16.932	3	1	4
APR-25	128.039	135.000	6.961	3	2	5
MAY-25	107.967	105.340	-2.627	1	3	4
JUN-25	219.123	151.209	-67.914	4	1	5
JUL-25	164.409	177.313	12.904	6	0	6
AUG-25	127.790	155.518	27.728	5	0	5
SEP-25	216.590	233.120	16.530	7	2	9
OCT-25	85.592	77.296	-8.296	1	3	4

Source: Company Operational Data, 2025

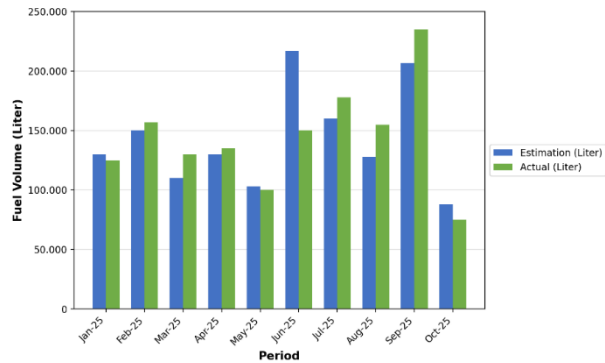


Figure 1. Comparism of Estimates and Actual Fuel Consumption per Period
Source: Company Operational Data, 2025

Table and Figure 1. displays operational data from 61 voyages carried out by several fleet units from January to October 2025, covering the main operational routes in the waters of Kalimantan, Sulawesi, Java to Papua. The data includes Port of Loading (POL), Port of Discharge (POD), estimated fuel consumption (liters) based on crew reports, and the difference obtained from calculations using the calculation formula: $\text{Difference} = \text{Reality} - \text{Estimate}$. A positive difference value indicates over-consumption, while a negative value indicates under consumption. The significant difference in ship fuel consumption during the 2025 voyage period (January - October) shows the difference between fuel consumption generated through crew calculations and estimated data carried out during the period from January to October 2025. Based on the results of data collection and analysis, there is a very significant difference with this high difference indicating a discrepancy between the calculated data and reporting in the field.

These differences can be caused by several factors, such as inaccurate manual recording by the crew, late reporting, potential human error, and the possibility of undetected fuel loss. Furthermore, operational factors such as weather conditions, shipping routes, and ship loads can also affect actual consumption, which is not fully reflected in the calculation model. This indicates that the calculation and use of a fuel consumption monitoring system using a tracking system in the form of a Vessel Monitoring System (VMS) plays a significant role in increasing the transparency and accuracy of fuel consumption data and can be used as an evaluation tool for the reliability of manual reporting in the field.

The existence of this phenomenon causes central management to experience obstacles in identify operational inefficiencies early, so that fuel waste reaching 10-20% of total consumption cannot be detected after consumption occurs (FAO, 2018). Another problem will also arise when the manual recording system is unable to pro-vide a daily crew logbook that is prone to human error, when the crew checks the daily fuel consumption records, where there are errors in writing down fuel consumption. This study was conducted to describe the effectiveness of the fuel monitoring process using a vessel tracking system in the form of a Vessel Monitoring System (VMS) based on numerical data, such as ship speed during the voyage (in knots), the total distance of

the ship's route using nautical miles (nm) and fuel usage obtained through fuel filling data (bunker request) as an estimate of consumption calculations. This approach allows researchers to provide an objective picture of the actual conditions of the system implementation without conducting other relationship tests. A descriptive explanation was chosen because the research object company already has a recording system, including shipping routes, ship speeds and estimated fuel consumption from bunker request calculations, thus allowing an objective analysis of monitoring effectiveness with available data.

Based on the context of the research location, it is necessary to formulate a clear direction of the study so that the research process can run in a structured manner and focus on the main problems identified through the effectiveness carried out in the Company's operational activities and the use of VMS in measuring fuel consumption. Therefore, this study aims to analyze and describe the effectiveness of the fuel consumption monitoring process using a tracking system in the form of a Vessel Monitoring System (VMS) in the company's operational activities as a basis for determining the scope of the analysis and the expected contribution of the results of this study. Therefore, the researcher conducted a study with the theme entitled "Analysis of the Effectiveness of Monitoring Ship Fuel Consumption at PT XYZ in Jakarta Using a Vessel Monitoring System (VMS) in 2025".

2. Literature Review

2.1 Marine Transportation Management

Maritime transportation management is an integral part of the global logistics system, encompassing operational, commercial, and strategic management of ship-ping activities. In the context of shipping and ship chartering, this management focuses not only on ship operations but also includes asset management, fleet planning, and decision making related to ship charter contracts. According to (Lambrou et al., 2019), modern shipping management involves various functions such as fleet planning, service planning, and chartering, all of which play a role in enhancing a company's competitiveness. In recent developments, maritime transportation management in Indonesia has also begun adopting digital systems to support the management of shipping activities. (Margaretha et al., 2024) explain that digitalization in the maritime sector, such as the use of shipping information systems and ship tracking, has begun to be implemented to improve data management and coordination between parties in maritime transportation. Overall, maritime transportation management in Indonesia is a shipping system management process that involves various components such as ships, ports, route networks, and government policies. This system is integrated to support connectivity between stakeholders.

2.2 Fuel Consumption Monitoring

Fuel consumption monitoring is a crucial component of ship operational control as it provides information on fuel usage during a voyage. In shipping and chartering activities, fuel consumption is influenced by various factors, such as ship speed, weather conditions, cargo load, and engine characteristics. Therefore, a system capable of

providing accurate and continuous data is required. Marijan et al. (2025) explain that the use of maritime data, including ship tracking data, allows for more systematic and measurable fuel consumption estimation and monitoring. In time charter contracts, fuel consumption monitoring also serves as a basis for verifying compliance with the terms of the contract between the shipowner and charterer.

The development of digital technology has encouraged the implementation of data-driven monitoring systems that can improve the quality of ship operational information. Fan et al. (2024) stated that a data-driven approach allows for more accurate identification of fuel consumption patterns as a basis for operational evaluation. Furthermore, Alavi-Borazjani et al. (2025) explained that the concept of smart ship-ping integrates various monitoring systems into a single digital platform, allowing for more transparent and sustainable access to ship operational information. Thus, tracking systems such as the Vessel Monitoring System (VMS) not only function to monitor ship position but also have the potential to become a source of operational data for fuel consumption analysis.

2.3 Vessel Monitoring System (VMS)

A Vessel Monitoring System (VMS) is a satellite-based ship monitoring system that integrates positioning, communication, and data processing devices to provide accurate information on a ship's location and activity (FAO, 2018). In shipping operations, a VMS functions as an information system that collects, transmits, and processes ship data into information that can be used for operational monitoring and decision-making (Bachtiar, 2022). In Indonesia, a VMS has been implemented as part of a ship monitoring system to support regulatory compliance and improve control of shipping activities. With the development of digital technology, a VMS is also integrated with the Internet of Things (IoT), data analytics, and maritime information systems, thus providing real-time operational data to support ship activity analysis. Sitanggang et al. (2024) stated that the integration of tracking systems allows the use of ship position and speed data to support prediction and voyage planning. Thus, a VMS functions not only as a ship tracking tool but also as a source of operational data that can be used to support the monitoring and analysis of ship fuel consumption.

2.4 Use of Tracking System on Ships

The development of digital technology has expanded the concept of effectiveness through the use of information systems to support operational processes. Ferdiyatomoko and Kumoro (2026) explain that the implementation of digital technology can improve service effectiveness, transparency, and the quality of decision-making if supported by the organization's ability to integrate and utilize information optimally. These findings provide a basis for the potential for technology based tracking systems, such as the Vessel Monitoring System (VMS), to improve the effectiveness of operational monitoring by providing accurate and timely data. Furthermore, Zebua et al. (2024) state that the use of data and analytics contributes to improving the quality of data-driven decision-making. In the context of this study, the effectiveness of a VMS is reflected

in its ability to provide real-time ship operational data that can be used as a basis for monitoring and analyzing ship fuel consumption.

2.5 Effectiveness of Fuel Consumption Monitoring

Fuel consumption monitoring is a crucial component of maritime transportation operational management, providing information used to evaluate fuel usage during voyages. A monitoring system capable of producing accurate, consistent, and timely data serves as the basis for fuel consumption analysis and supports operational decision making. Conversely, a system with a low level of accuracy can potentially produce information that is less representative of actual conditions in the field (Pleskach, 2022). Furthermore, the high variation in fuel consumption due to differing operational conditions demands a monitoring system capable of providing reliable and continuous data (Briers, 2019).

In maritime transportation, fuel consumption is influenced by various factors, such as ship speed, weather conditions, route characteristics, and cargo load. Therefore, monitoring fuel consumption requires a system capable of continuously integrating ship operational data. Xiao et al. (2025) demonstrated that data-based monitoring of ship operations can improve the quality of fuel consumption analysis, while Yuan et al. (2021) explained that real time consumption data is the basis for developing ship energy consumption prediction models.

One technology that can be utilized is the Vessel Monitoring System (VMS), a ship tracking system that provides real-time information on position, speed, route, and voyage duration (Bachtar, 2022). In addition to functioning as a tracking tool, a VMS has the potential to be a source of operational data for fuel consumption analysis. The effectiveness of monitoring using a VMS can be assessed by the system's ability to produce accurate, timely, and consistent data. Nari et al. (2025) stated that integrating ship operational data improves the quality of fuel consumption analysis, while Liu et al. (2026) emphasized that providing real-time data supports the ongoing monitoring process. Thus, the quality of data generated by a VMS is a critical factor in evaluating the effectiveness of a ship's fuel consumption monitoring system.

3. Methods

This research uses a quantitative approach with descriptive methods. The quantitative approach was chosen because it emphasizes measuring research variables in the form of numerical data, which are then analyzed using statistical data. This approach allows researchers to objectively and measurably examine the relationship between the process of monitoring ship fuel consumption and the Vessel Monitoring System (VMS) tracking system. According to Jaya (2020), research using a quantitative approach focuses more on several phenomena that have certain characteristics in human life, namely variables.

This study utilizes secondary data obtained directly from the company's operational system. The research data was obtained from the historical VMS tracking system for 2025. Supporting documents related to the analysis include shipping data, fuel consumption, travel routes, and ship speed. The data obtained is essentially related to ship

shipping activities and fuel consumption. The analysis focuses on the number of shipments departing from a specific loading port between January and October 2025. The data displayed in the VMS tracking system includes the vessel name, date information, vessel location, vessel speed, and other information. Other data to support statistical calculations for comparison include fuel consumption calculations sourced from bunker request documents, which serve as additional calculation material for estimating fuel consumption. The obtained data will then be analyzed quantitatively using descriptive statistical analysis techniques to describe the operational conditions of the voyage and the level of fuel consumption for each activity.shipping. This study also used a technique for data collection in the form of interviews based on the use of purposive sampling techniques, where researchers conducted observations in the form of direct interviews based on predetermined criteria.

4. Results and Discussion

4.1 Effectiveness of Fuel Consumption Monitoring in VMS Operations and Implementation

The effectiveness of fuel consumption monitoring in operational activities can be understood as a system's ability to provide more complete, accurate, consistent, and timely data that can be used as a basis for monitoring and analyzing fuel usage. This effectiveness is not solely determined by data availability, but also by the regularity of recording, the suitability of system data to actual conditions, and the tracking system's capacity to generate information that supports operational analysis. This study is based on the view (Guerra-López & Thomas, 2011) that an effective information system is one that produces valid and reliable data to support decision-making, reinforced by (Sugiyono, 2023) who emphasized that good data must meet the elements of completeness, consistency, and assurance. Empirically, (Shi et al., 2020) proves that an integrated real-time monitoring system is capable of providing continuous consumption data and facilitating ship operational evaluation. (Yusuf et al., 2025) showed that sensor-based and IoT approaches improve recording accuracy compared to manual methods, while (Wu et al., 2023) emphasized that the completeness of operational data is a major factor in the reliability of fuel consumption analysis.

4.1.1 Fuel Consumption Data Availability

The availability of fuel consumption data is one indicator in assessing the effectiveness of ship fuel consumption monitoring. This indicator relates to measurement accuracy, the ability to provide adequate data, and consistent calculation standards. Conceptually, data availability refers to the extent to which required data is available in a complete, continuous, easily accessible, and ready to be used for analysis and decision-making processes. Based on field findings through in-depth interviews with informants, it was found that the availability of fuel consumption data in the company has been carried out routinely and structured. Informants revealed that fuel usage recording is carried out daily by referring to the company's internal calculation standards, and the results are reported to the office through a daily reporting mechanism known as the

Noon Report. This report is consistently sent every afternoon as an integral part of the ship's daily operational report, thus reflecting the existence of a recording system that runs continuously and can be used as a primary data source in operational fuel consumption monitoring.

Based on the results of observations and theoretical studies that have been presented, it can be concluded that the manual fuel consumption recording system in this shipping company does not fully meet the data quality standards required by (Guillen-Aguinaga et al., 2025), namely availability, completeness, accuracy, consistency, and timeliness. Dependence on the accuracy of the ship's crew, the potential for reporting delays, and the possibility of deviations between reported data and actual conditions in the field are structural obstacles that directly affect the quality of the fuel consumption monitoring and evaluation process.

In line with the findings of Shi et al. (2020), which emphasized that comprehensive and integrated ship operational data can improve the accuracy of fuel consumption monitoring, the use of a Vessel Monitoring System (VMS) as an analytical instrument is considered relevant and strategic. VMS provides system-based operational data covering speed, distance traveled, and voyage duration variables directly correlated with fuel consumption but not yet optimized in current monitoring practices. This condition is reinforced by Yusuf et al. (2025), who demonstrated that a digital-based monitoring system can significantly improve recording accuracy while simplifying the operational evaluation process.

Thus, the integration of VMS data into the fuel consumption monitoring system is not merely a technical improvement, but rather a substantive step towards more objective, verified, and data-driven operational governance. Optimal utilization of VMS has the potential to strengthen the company's capacity to cross-verify manual crew reports with system track records, allowing for more structured, accountable fuel consumption analysis and adherence to the principles of effective ship operational control

4.1.2 Daily Recording and Reporting Frequency

The frequency of daily recording and reporting is an indicator that reflects the level of regularity and timeliness in providing fuel consumption data. Within the framework of data quality, this aspect is closely related to the dimension of timeliness, namely the ability of a system to provide data periodically and in a timely manner so that the resulting information remains relevant for monitoring and operational decision-making. (Alabduljabbar, 2024) explains that timeliness is one of the main dimensions of data quality, where the availability of data periodically and on time is a prerequisite for the information to be used effectively in the monitoring process. The higher the recording frequency and the more consistent the reporting, the greater the company's ability to detect changes in fuel consumption patterns quickly and accurately.

Based on the results of in-depth interviews with informants, it was found that the recording and reporting of fuel consumption at the company has been carried out routinely every day as part of the applicable operational procedures. Fuel usage data is recorded by the ship's crew based on engine activity and daily operational conditions, which is then used as the basis for calculating consumption for monitoring and evaluation purposes by management. After the recapitulation process is completed, the report

is sent to the office every afternoon, so that management can receive fuel consumption information periodically and continuously as part of the ship's operational control.

Observations indicate that the current fuel consumption calculation approach is sufficient as an operational reference, but does not fully reflect actual consumption because the resulting data is estimated and not the result of direct measurements. Technically, the relationship between engine Revolutions Per Minute (RPM) and ship speed on fuel consumption levels is acceptable, where decreasing RPM and speed will reduce consumption, while increasing them will have the opposite effect. However, manual calculations have inherent limitations because they do not take into account all variables of actual conditions in the field, such as weather, ocean currents, ship load, and engine operating patterns, so the frequency of daily recording that has been running does not fully guarantee the accuracy of the resulting data.

In the context of ship operations, daily recording and reporting continue to provide significant benefits because they enable companies to obtain a continuous overview of fuel consumption patterns, which in turn facilitates the planning process and identifies potential inefficiencies. However, the limitations of manual estimation methods drive the need for more objective supporting instruments. In this regard, utilizing operational data from the Vessel Monitoring System (VMS) is considered to have the potential to provide more measurable information and can be used as a validation tool for fuel consumption calculations that have been performed manually. Data available in the VMS, including speed, position, distance traveled, and voyage duration, are variables that are directly correlated with fuel consumption and can be utilized to generate real-time, system-based consumption estimates.

The potential use of VMS as a fuel consumption monitoring instrument is supported by several empirical studies. Yusuf et al. (2025) demonstrated that IoT-based monitoring systems can improve the accuracy and continuity of fuel consumption data, while Shi et al. (2020) confirmed that digital monitoring systems produce higher data accuracy than manual recording. Furthermore, (Işıklı et al., 2020) demonstrated that operational variables such as speed and sailing distance significantly influence ship fuel consumption. Therefore, integrating VMS data into a company's monitoring system has strong potential to strengthen the analysis process, increase the objectivity of data verification, and support more effective and evidence-based control of ship fuel consumption.

4.1.3 Data Conformity (System and Actual)

Data conformity between the system and actual conditions is an indicator that shows the level of match between the data generated by the monitoring system and the actual conditions occurring in the field. In data quality theory, this concept is closely related to the dimensions of accuracy and consistency. In this study, data conformity is defined as the level of match between the estimated fuel consumption calculated based on operational data from the Vessel Monitoring System (VMS), such as speed, distance traveled and sailing duration with the fuel consumption data reported by the ship's crew through the logbook.

Interviews with informants confirmed that deviations between system data and manual crew reporting are common in fuel consumption monitoring practices. These differences are considered normal, given that the reported data is still estimated and relies heavily on the crew's experience and subjective judgment in estimating fuel consumption based on engine RPM, vessel speed, and the company's established liters per hour standard. Consequently, reported fuel consumption patterns tend to follow general operational conditions, but the recorded figures do not fully represent actual fuel usage in the field.

Technically, the engine RPM-based approach can produce a reasonable estimate for operational reference, but it has fundamental limitations because it does not account for other operational factors that influence fuel consumption, such as weather conditions, ocean currents, ship load, and the use of auxiliary engines. This is in line with the view of Guillen-Aguinaga and Aguinaga-Ontoso (2025), who emphasized that quality data must meet the elements of validity, accuracy, timeliness, and consistency to be used reliably in monitoring and decision-making processes. In the context of this research, these findings indicate that the aspects of accuracy, namely the extent to which data represents actual conditions, and consistency, namely the uniformity of data between sources, are not fully met in the current manual reporting system. The smaller the deviation between reported data and actual conditions, the higher the level of confidence in the resulting analysis results.

Based on these findings, the use of the Vessel Monitoring System (VMS) as a more objective source of operational data is becoming increasingly relevant and strategic. The data available in the VMS, including speed, distance traveled, and voyage duration, can function as a comparison instrument (cross-validation tool) to validate the results of fuel consumption calculations that have been carried out manually by ship crews. By integrating these two data sources, companies have the potential to obtain a more accurate, verified, and scientifically accountable picture of fuel consumption, thereby supporting a more effective and data-driven ship operational control process (data-driven decision-making).

4.2 Use of Vessel Monitoring System (VMS) in Measuring Fuel Consumption

The use of a Vessel Monitoring System (VMS) in measuring fuel consumption is based on the system's ability to automatically record ship operational data, including position, speed, distance traveled, and voyage duration. These variables have a direct correlation with fuel consumption levels, so they can be used to produce more objective consumption estimates than manual recording methods. This aligns with the findings of Shi et al. (2020) who confirmed that ship operational variables, particularly speed and voyage conditions, significantly influence fuel consumption and can be used as a basis for more accurate analysis. Thus, a VMS not only functions as a tool for monitoring ship position but also serves as a source of operational data that supports the systematic calculation and verification of fuel consumption.

The relationship between ship speed and fuel consumption has been empirically proven in various studies. (Zhou et al., 2024) showed that speed is the variable that most influences fuel consumption, where increasing ship speed directly increases engine load and fuel consumption. This finding is supported by research in the field of

Artificial Intelligence applications in ship navigation, which found that speed optimization and route selection can reduce fuel consumption by 15–25%. In the context of this study, a speed-based fuel consumption calculation model was carried out by connecting speed data from the VMS with the standard liter consumption per hour set by the company, using the following formula approach:

$$\text{Fuel Consumption} = \text{Standard Consumption (liters/hour)} \times \text{Operation Duration (hours)}$$

Operation duration is derived from VMS tracking data, while interpretation of the results takes into account variations in vessel speed as a determining factor in consumption levels. This approach allows companies to compare consumption estimates based on operational data with actual crew reports, making the monitoring process more measurable and accountable.

The use of VMS as a fuel consumption analysis instrument is supported by several relevant empirical studies. Yusuf et al. (2025) demonstrated that digital and Internet of Things (IoT)-based monitoring systems can provide real-time and continuous fuel consumption data, thereby increasing accuracy and simplifying the operational evaluation process. Shi et al. (2020) added that digital monitoring systems are more consistent than manual recording because the data is obtained automatically and can serve as a basis for verification. Guillen-Aguinaga and Aguinaga-Ontoso (2025) also emphasized that the integrity of ship operational data is a key factor in improving the reliability of fuel consumption analysis. Based on these theoretical and empirical foundations, VMS in this study is seen as a potential instrument for linking ship operational data with fuel consumption calculations, allowing the monitoring process to be carried out in a more objective, structured, and data-driven manner.

4.2.1 The Relationship Between Tracking Data and Fuel Consumption

The relationship between ship tracking data and fuel consumption is based on the principle that fuel consumption is significantly influenced by ship operational parameters, particularly speed, distance traveled, and voyage duration. The Vessel Monitoring System (VMS) used in company operations automatically and continuously records all of these parameters, allowing the resulting data to theoretically serve as a basis for more objective fuel consumption estimates. Zhou et al. (2024) asserted that operational variables such as speed, distance traveled and voyage duration have a direct and significant relationship to ship fuel consumption levels, while Guillen-Aguinaga and Aguinaga-Ontoso (2025) added that digital monitoring systems can improve data accuracy and consistency compared to manual recording approaches.

However, in-depth interviews with informants revealed that, to date, there is no direct link between VMS data and the process of recording and reporting fuel consumption at the operational level. The VMS system is still used exclusively to monitor vessel position and movement, while fuel consumption reporting remains performed manually by crews based on engine hours. This situation indicates a gap between the potential of the available system and its actual use in fuel consumption monitoring.

These findings also demonstrate that the company essentially has two complementary sources of information: operational tracking data from the VMS and consumption data manually recorded by the ship's crew. If these two data sources are integrated, the VMS has great potential to function as a validation and analysis instrument that

strengthens the objectivity of fuel consumption monitoring. This integration will not only improve data accuracy but also enable the company to cross-verify system-based consumption estimates with actual crew reports, thus enabling a more structured, accountable, and data-driven operational decision-making process.

4.2.2 Analysis of The Relationship Between Speed and Consumption

The analysis of the relationship between ship speed and fuel consumption is based on the hydrodynamic principle that increasing speed will increase the ship's resistance in the water non-linearly, so that the engine must work harder and fuel requirements increase proportionally. Technically, this condition is reflected in the relationship between the engine's Revolutions Per Minute (RPM) and the level of fuel consumption, where the increase in RPM in response to the increase in speed directly impacts the increase in the amount of fuel used during the voyage.

Interviews with crew members confirmed that a ship's operational speed is not constant, but is strongly influenced by field conditions, particularly weather and ocean currents. When water conditions are unfavorable, such as strong currents or high waves, the ship's engine tends to operate at higher RPMs to maintain speed, significantly increasing fuel consumption. Conversely, calm sea conditions with favorable currents allow the ship to operate at lower RPMs, which in turn results in more efficient fuel consumption. Thus, ship speed, influenced by various external factors, particularly weather and ocean currents, has a strong positive correlation with engine workload and fuel consumption levels during the voyage.

These field findings align with the theoretical basis proposed by Zhou et al. (2024), who stated that ship speed is the most dominant factor in fuel consumption prediction models, where increasing speed is consistently followed by a measurable increase in consumption. This is reinforced by research in the field of Artificial Intelligence applications in ship navigation, which proves that optimal speed settings and efficient route selection can reduce fuel consumption by 15–25%. Furthermore, research on the effects of tidal currents shows that adjusting a ship's effective speed to current conditions can increase fuel efficiency by up to 2.46%. These findings collectively emphasize that speed analysis is a crucial element in understanding ship fuel consumption patterns.

4.2.3 Speed-Based Fuel Consumption Calculation Model

The speed-based fuel consumption calculation model is a quantitative approach that utilizes ship operational data, including average speed, voyage duration, and engine consumption standards (liters/hour), to produce a more structured and objective estimate of fuel usage. The theoretical basis of this approach refers to the cubic law of fuel consumption principle in naval architecture, which states that fuel consumption increases cubically as ship speed increases. This is confirmed by Zhou et al. (2024) who proved that speed is the most dominant operational variable in the fuel consumption prediction model, where increasing speed is consistently followed by a measurable increase in consumption.

In this study, the calculation model is formulated based on two main variables obtained in real-time from the GPS/AIS device installed on the ship, namely the average speed of the ship in knots known as Speed on Ground (SOG), and the sailing distance

from the Port of Loading (POL) to the Port of Discharging (POD) in Nautical Miles (Nm). The average speed is calculated from the total accumulated speed during the voyage divided by 24 hours as a conversion of sailing days, as read by the VMS system. This approach assumes that fuel consumption is proportional to the speed and distance traveled by the ship.

In the practical implementation of this study, VMS uses a linear approach based on the product of speed times distance ($\text{speed} \times \text{distance}$) without additional weighting coefficients such as load condition coefficients or weather factors. This condition is a critical aspect that needs to be considered in the interpretation of the results, considering that not all external variables that affect fuel consumption, such as ocean currents, weather conditions, ship load, and the use of auxiliary engines, are taken into account in the model. As stated by informants, tracking data from the system is not always completely accurate because under certain conditions it can experience deviations due to signal interference, transmission delays, or imperfections in recording the ship's position and speed.

Based on these considerations, the speed-based fuel consumption calculation model is deemed suitable for use as a supporting analysis instrument, but cannot be positioned as the sole source of information in the monitoring process. VMS tracking data should be integrated in a complementary manner with the company's internal calculation formula, consumption standard memorandum, and actual crew reports, so that the analysis results obtained are more objective while still considering the possibility of system data errors. This view is in line with the informant's statement that the success of VMS implementation as an analysis tool depends not only on the availability of technology, but also on the readiness of human resources, clear division of tasks, and support from company managerial policies.

The VMS monitoring data used in this study covers 49 shipments from January to October 2025, covering various shipping routes in Indonesian waters, particularly Kalimantan, Sulawesi, Java, and Papua. Each data entry contains route information (POL–POD), sailing distance, average speed, sailing duration, estimated consumption calculated from the VMS, estimated consumption based on the company's budget, manual crew reports via noon reports, and accuracy percentages as an indicator of data conformity. Thus, the integration of VMS data and manual crew reports provides a more comprehensive basis for analysis, allowing companies to monitor fuel consumption in a more structured, accountable, and data-driven manner to support the effectiveness of ship operational control. The following graph shows the trend percentage accuracy of the resulting VMS calculations.

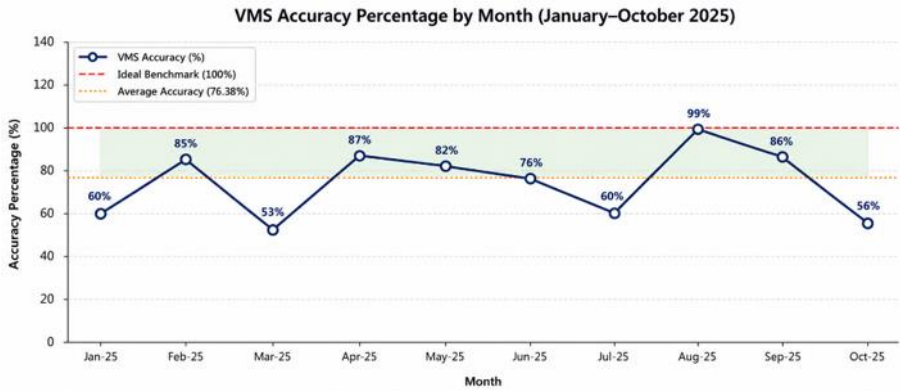


Figure 2. Tren of Percentage Accuracy of VMS Calculations against Manual Report Ship Crew per Period (Jan – Oct 2025)

Source: Data Processed by Researchers, 2026

Figure 2 shows the percentage accuracy of VMS calculations compared to individual crew manual reports per voyage. Green bars indicate voyages with reasonable accuracy ($\leq 100\%$), while red bars indicate voyages with overestimation ($> 100\%$). The wide variation in accuracy ranging from 1% to 212%—reflects differences in route characteristics, operational conditions, and data availability between voyages. Voyages with very low accuracy typically occur on short routes or with incomplete data, while voyages with very high accuracy indicate significant differences in calculation assumptions between the VMS system and the crew's manual records.

Significant inaccuracies, either underestimation or overestimation. Identified primarily on: (a) very short-distance routes (< 100 Nm), where the proportion of time the vessel is in maneuvering, loading and unloading or idling conditions is more dominant; (b) very long-distance routes (> 1500 Nm) such as Jakarta Merauke, which are likely to be affected by variations in sea conditions, differences in draft and changes in wind speed; (c) long-duration voyages (> 30 days) which increase the possibility of deviation from normal sailing conditions.

A comparison of fuel consumption based on VMS calculations, shipment budgeting estimates, and manual crew reports revealed differences in each recording method. The company's budgeting estimate tended to be higher because it took into account fuel consumption during the ship's movement to the loading port, the towing process after unloading, and the waiting time before the next voyage. Meanwhile, on several voyages, crew-reported fuel consumption was lower than the VMS estimates, indicating potential underreporting in manual recording. Furthermore, an evaluation of the VMS data also revealed incomplete recording in several periods, as shown in Table 2, where data was not recorded for November 15–December 17, 2025, on the S14/15 vessel and data only covering 12 hours on September 2, 2025, on the S16/17 vessel. These findings indicate that both manual recording and the VMS system still have limitations that need to be considered in the evaluation of ship fuel consumption.

Table 2. Results of Documentation Record Findings of Ship Systems 14 and 16

VesselNar	DateTime(GMT)	Speed(Knot)	VesselNar	DateTime(GMT)	Speed(Knot)
14	14/11/2025 18.19	0,00	16	02/09/2025 00.05	27.898.528.000.000.000
14	18/11/2025 12.22	1992752000000000,00	16	02/09/2025 11.27	30.887.656.000.000.000
14	18/11/2025 13.22	2789852800000000,00	16	02/09/2025 12.27	28.894.904
14	18/11/2025 14.22	2690215200000000,00	16	02/09/2025 13.27	30.887.656.000.000.000
14	18/11/2025 15.22	25905776,00	16	02/09/2025 14.27	28.894.904
14	18/11/2025 16.22	2789852800000000,00	16	02/09/2025 15.27	31.884.032
14	18/11/2025 17.22	2789852800000000,00	16	02/09/2025 16.27	32.880.408
14	18/11/2025 18.22	2789852800000000,00	16	02/09/2025 17.27	32.880.408
14	18/11/2025 19.22	2789852800000000,00	16	02/09/2025 18.27	33.876.784.000.000.000
14	18/11/2025 20.22	2690215200000000,00	16	02/09/2025 19.27	31.884.032
14	18/11/2025 21.15	25905776,00	16	02/09/2025 20.27	30.887.656.000.000.000
			16	02/09/2025 21.27	32.880.408

Source: Company Operational Data System VMS, 2025

Based on an analysis of shipments during the January–October 2025 period, the speed-based fuel consumption estimation model applied to the Vessel Monitoring System (VMS) produced an average accuracy of 76.38% compared to manual crew consumption reports. These results indicate that the tracking data generated by the VMS can be used as a basis for monitoring ship fuel consumption. However, the variation in accuracy between shipments is still quite large, indicating that the speed-based model is not fully able to represent the operational conditions of the ship. This difference is thought to be influenced by several factors, such as cargo conditions, weather and ocean currents, shipping route characteristics, engine condition, and potential discrepancies in manual recording. Therefore, the development of the VMS model through a more comprehensive integration of operational data, such as cargo data, weather parameters, and real-time flow meter readings, has the potential to improve the accuracy of ship fuel consumption estimates.

5. Conclusion

The results of the study indicate that the ship fuel consumption recording system at PT XYZ is still dominated by manual reporting through the Noon Report, thus potentially causing deviations due to human error and the suboptimal utilization of ship operational data as a basis for analysis. Although the Vessel Monitoring System (VMS) has provided continuous information on position, speed, route, and sailing duration, the system has not been optimally utilized for monitoring fuel consumption. Based on an analysis of 49 shipments, it was found that the ship speed variable has a significant relationship with fuel consumption and can be used as a basis for estimation through the VMS with an average accuracy level of 76.38%. However, the accuracy of the model is still affected by the limitations of the speed-based approach, especially in non-standard operating conditions, such as low-speed sailing, idling activity, ship maneuvers, and variations in route characteristics. Therefore, the development of the VMS through the integration of more comprehensive operational data, such as RPM data, cargo conditions, weather, and flow meters, is needed to improve the reliability of ship fuel consumption monitoring.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article

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